A PHOTOELASTIC APPROACH TO MEASURE RESIDUAL STRESSES IN CIRCULAR TUBES OF POLY(METHYL METHACRYLATE) (PMMA) AND TO EVALUATE THE INFLUENCE OF VARIOUS PARAMETERS ON THEM

BY

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THE DEGREE OF
DOCTOR OF PHILOSOPHY

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dedicated to

MY WIFE AND CHILDREN

CERTIFICATE

This is to certify that the thesis entitled "A PHOTO-ELASTIC APPROACH TO MEASURE RESIDUAL STRESSES IN CIRCULAR TUBES OF POLY(METHYL METHACRYLATE) (PMMA) AND TO EVALUATE THE INFLUENCE OF VARIOUS PARAMETERS ON THEM" being submitted by Mr. IRSHAD AHMAD KHAN to the Indian Institute of Technology, Delhi for the award of the Degree of DOCTOR OF PHILOSOPHY is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the standard fulfilling the requirements for the award of the degree of Doctor of Philosophy.

The research report and the results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Extruded tubes of transparent polymeric materials such as poly(methyl methacrylate) (PMMA) are replacing glass tubes in engineering practice since the former is less brittle. However, during extrusion process residual stressess are produced which are generally detrimental to the performance of these tubes. They degrade the resistance to external loads, heat distortion and environmental stress cracking, etc. On the contrary, in certain applications they are intentionally produced, an example being the presence of compressive stressess on the surfaces in order to improve fracture resistance. A knowledge of these stresses is, therefore, an important factor in the assessment of long-term serviceability of the product.

The most commonly employed experimental technique for the measuremnt of residual stresses is the layer removal technique which is destructive in nature and quite time consuming. Also, so far its application has almost been restricted to rectangular bar specimens only. However, if this technique is employed for circular tubes or rods, the deformations produced by the removal of layers and their analysis are quite different from those of rectangular bar specimens. Further, although the technique can be applied for circular rods if the diameter is not very small, there are several difficulties in applying it for the thin-walled tubes.

In view of these difficulties, a photoelastic technique has been used in the present work to determine residual stresses in circular tubes of PMMA which exhibits photoelastic effects. This technique was originally suggested by O'Rourke and Saenz in order to measure residual stresses in glass cylinders and spheres. Recently, the technique has been adapted for circular rods of transparent polymers. This technique basically involves the measurements of total relative retardations at various points across the thickness of a tube or the diameter of a rod. These measurements can easily be carried out on a standard polariscope.

The theoretical analysis of the technique shows that the total retardation across any chord is dependent only on the axial stress in a long specimen (assuming plane strain conditions) provided the stress-state is in equilibrium as is the case with residual stresses. The theoretical analysis results in Abel's integral equation, the solution of which is well known. However, due to some mathematical difficulties in using the analytical solution, a numerical procedure has been adopted to obtain the results. This procedure requires an accurate assessment of axial stress at the outer surface. A systematic way to obtain this stress has been discussed. In order to obtain other components of residual stresses, i.e., radial and hoop components, the assumption of the "sum rule" of stresses has been employed.

To utilize the capabilities of the photoelastic technique such as its being quick and nondestructive in nature, it was employed to study short-term relaxation phenomenon associated with quenching stresses. The results show that the relaxation occurs mainly in the core region of the specimen. The rate of relaxation is higher in the beginning.

To establish the relative advantages of the photoelastic technique, its results were compared with those obtained by the layer removal and sectioning techniques. In layer removal technique, thin layers of uniform thickness are removed by machining the surface of rod or tube and measuring the deformation produced. This deformation can be correlated with the distribution of residual stresses. For this purpose an analysis based on some kinematic assumption is available in literature. Replacing this assumption by the sum rule of stresses, much simpler expressions have been obtained. Moreover, since the photoelastic technique also makes use of the same assumption, the comparison between the two techniques becomes more meaningful.

In the sectioning technique, the difference of radial and hoop components of residual stresses is obtained by direct photoelastic analysis of a ring cut from the end of a tube. In this case, however, no information is directly available about the axial component of the residual stresses, which is generally the most significant component.

From the comparative study of all the three experimental techniques, it may be concluded that the photoelastic technique is the most suitable technique for the measurement of residual stresses in transparent polymeric tubes or rods. It is easily applicable and capable of producing a full distribution of residual stresses either through the thickness of a tube or the diameter of a rod. Further, it being nondestructive and quick, the technique may suitably be applied for the study of short-term stress relaxation phenomenon. The simplified version of this technique may be employed in polymer industry as a quality control tool.

The implications of this assumption have been examined and were found to prove the validity of the assumption.

The photoelastic technique was then employed to study the effects of some geometrical and thermal parameters on the magnitudes of residual stresses. These are: (i) the variation in the initial temperature, (ii) variation in the final temperature, (iii) tube wall thickness, and (iv) different cooling media.

It was observed, in general, that residual compressive stresses are formed at surfaces while tensile stress is formed in the core region of the specimen. The initial and final temperatures were shown to have a distinct effect on the magnitudes of the stresses. The magnitudes of both the stresses (compressive and tensile) are found to increase with either increasing initial temperature or decreasing final temperature. On the other hand, the variation in specimen thickness only affects the tensile stresses. They are found to increase with an increase in wall thickness. Cooling in different media also influences the magnitude of the stresses.

In order to further enhance the usefulness of the photoelastic technique, it has been simplified to an extent that only two measurements of total retardation are sufficient to obtain the maximum tensile and compressive stresses. Two empirical relations have been developed for this purpose. The results are within ± 10% of those obtained by the detailed analysis.

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